STANDARD OIL
ENGINEERED MATERIALS

Memorandum

To: S. C. DeSutter
C. T. Scholl

Date: 11/11/87

From: B. R. Gardner

B. R. G.

Copy to:

RECEIVED
NOV 11 1987
S. C. DeSUTTER

Subject: University of Nebraska Data

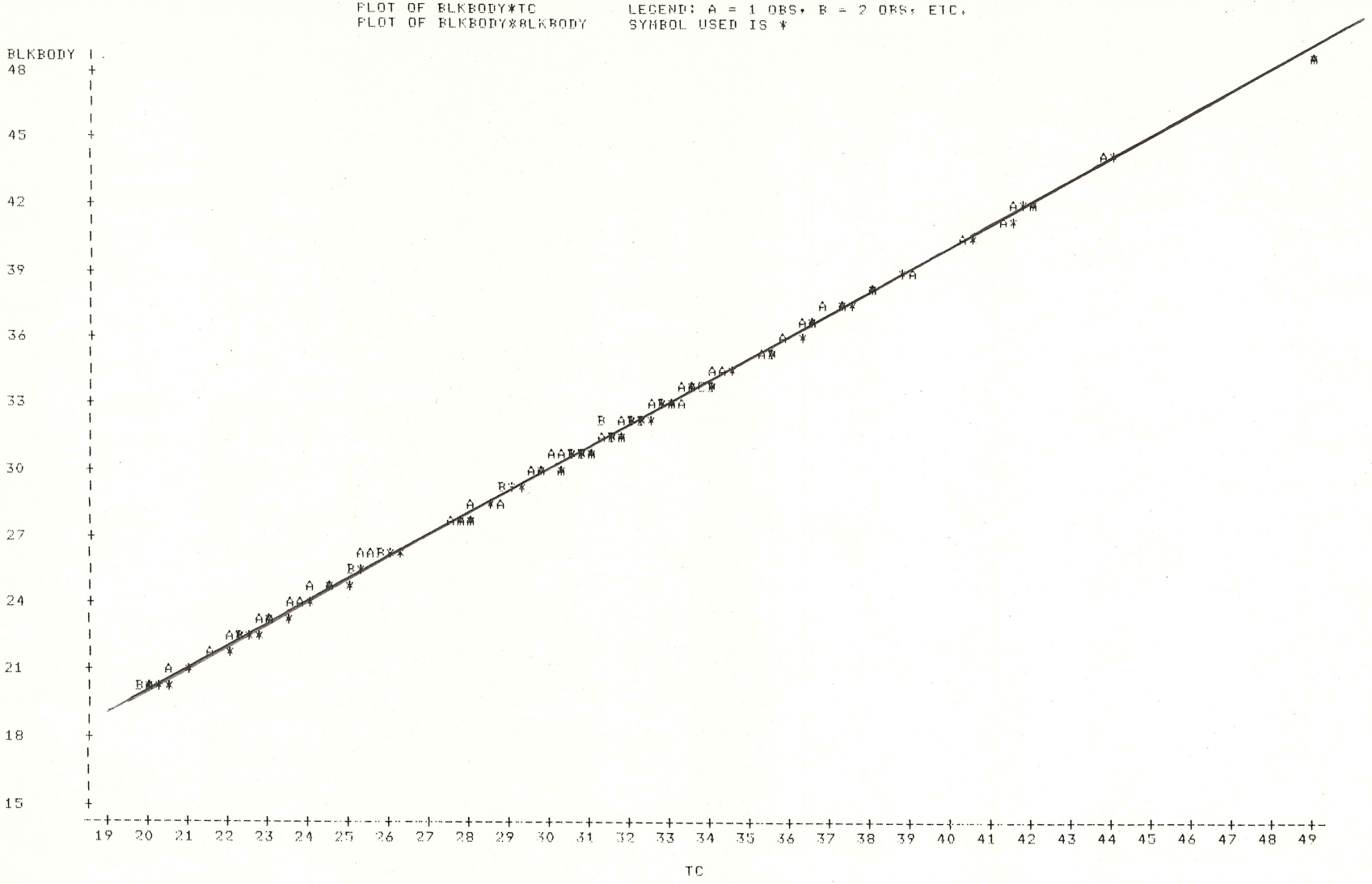
Dr. Blaine Blad has provided me with his field calibration data for the Scheduler^{R} Plant Stress Monitor he purchased. The Scheduler IRT was calibrated at field locations in the Konza prairie in Kansas during June, July and August. The calibration source used was manufactured by Everest. The results show that the Scheduler IRT is very accurate. This comes as no surprise, since the Scheduler IRT was engineered and tested rigorously. The data also confirms the validity of the transfer function and rate of change calculation contained in the Scheduler software. My compliments, Chuck.

SCD/lb

CALIBRATION OF THE SCHEDULER WITH AN EVEREST BLACKBODY
LOCATION: KONZA PRAIRIE • JUNE-AUGUST• 1987

PLOT OF BLKBODY*TC
PLOT OF BLKBODY%BLKBODY

LEGEND: A = 1 OBS, B = 2 OBS, ETC.
SYMBOL USED IS *



NOTE: 33 OBS HIDDEN

CALIBRATION OF THE SCHEDULER WITH AN EVEREST BLACKBODY
LOCATION: KONZA PRAIRIE , JUNE-AUGUST, 1987

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: BLKBODY

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	2679.13464960	2679.13464960	47270.53	0.0	0.998310	0.7626
ERROR	80	4.53413088	0.05667664		ROOT MSE		BLKBODY MEAN
CORRECTED TOTAL	81	2683.66878049			0.23806855		31.21951220

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TC	1	2679.13464960	47270.53	0.0	1	2679.13464960	47270.53	0.0

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT	0.77857018	5.47	0.0001	0.14245814
TC	0.98208177	217.42	0.0	0.00451702

Copy to Brown

Safford Agricultural Center
P.O. Box 1015
Safford, AZ 85548
21 December 1987

Tom Fairweather
ProAg Management
2211 N. Fine St.
Fresno, CA 93727

RE: Laboratory test on the Scheduler

Dear Tom,

I finally got down to the Water Lab in Phoenix to do the testing that I mentioned I had planned to do on the scheduler. The tests were performed in the following manner: the equipment was equilibrated in a constant temperature room at three temperatures (54-55, 82-83 and 103-105 deg. F) to simulate some of the conditions under which we work in the field, then at each equilibrated instrument temperature the IR gun was aimed at a black body radiation source which was increased from 0 to 70 degrees C in steps of 10 degrees. Measurements were also taken as the temperature was decreased from 70 to 0 in steps of 5 degrees to see if there was any hysteresis effect.

In the interest of time I am sending you a preliminary graphical summary of the data from the first part of the experiment only, the increase from 0 to 70 degrees. There don't seem to be any differences in the measurements as the temperature decreased, never-the-less I will send you more complete information as it becomes available.

Figure 1, shows the calibration curve of the current production model of the scheduler. The line is very straight from 20 to 60 degrees celsius for all three room temperatures.

Figure 2 shows the ambient temperature sensor on the gun compared with a mercury thermometer in the constant temperature room. The divergence from the line is small and may have been affected by our testing technique.

Figure 3 shows the percent deviation from the black body temperature that the three guns measured. The current model scheduler held its own compared to the other two instruments.

So, all in all, the Scheduler, without the external chopper that some say is necessary, seems to be an accurate machine.

I hope this answers some of the questions you have about the Scheduler. I feel that there is an art to using any of the IR thermometers for irrigation prediction, as well as the science, but they seem to be a good tool.

Sincerely

Lee J Clark

Lee J. Clark

Scheduler Calibration

17 Dec 87

104°F

Time	BB	Ta	Scheduler 1 Tan			Scheduler 2			IRT SN100	Tele Temp IRT SN 377	
	T_z	BB	Crop	Air	RH	Crop	Air	RH	T_{BB}	T_{BB}	T_{dif}
4:30											
16:28	0	39.7	34.3	104.3	19	32.4	102.8	13			1.1
16:31	10	39.6	52.2	104.6	19	50.3	103.7	13			11.4
16:33	20	39.8	70.4	105.2	20	68.2	103.3	13	18		20.5
16:35	30	39.8	88.1	105.2	20	86.8	103.2	13			30.4
16:37	40	39.8	105.6	105.3	20	105.4	104.7	13			40.7
16:39	50	39.9	123.1	105.5	20	123.5	103.4	14			50.0
16:42	60	40.2	140.9 / 139.6	105.6 / 105.7	20 / 20	141.4	104.7	14	19		59.6
16:44	70	40.1	158.6	105.9	20	158.9	104.1	14			69.0
16:47	65	40.2	149.6	106.3	20	150.2	105.4	14			64.3
16:48	60	40.5	141.2	106.5	20	141.8	104.5	14			59.7
16:52	55	40.5	132.3	106.7	21	132.6	105.4	14	185		54.8
16:54	50	40.5	123.5 / 124.7	106.6	21	123.7	105.9	14			50.1
16:56	45	40.8	114.7	106.9	21	114.5	105.8	15			45.5
16:58	40	41.1	106.0	107.1	21	105.3	106.1	15	20		40.7
17:00	35	41.0	97.3	107.2	21	96.1	106.5	15			35.6
17:03	30	41.1	88.4	107.4	21	86.6	105.9	15			30.5
17:05	25	41.2	80.1	107.5	21	77.6	106.7	15			25.6
17:07	20	41.3	70.5	107.7	21	68.2	105.9	15			20.9
17:10	15	41.4	61.9	107.9	21	59.2	106.9	15			16.4
17:14	10	41.8	52.6	108.4	21	50.1	107.2	15	20		11.5
17:17	5	41.6	44.4	108.3	22	40.9	105.8	15			6.4
17:20	0	41.8	34.6	108.3	21	32.7	106.5	15			1.5

Time	Ta	T_w	RH
16:33	40.6	21.4	18
16:42	41.0	22.0	19
16:50	41.4	22.4	18.5
16:58	41.7	22.8	20
17:14	42.3	23.4	20

starting to get irradiance

C Checkmate
P Printer

psychrometer moved closer to scheduler

Scheduler Model 1 - 86-107 rev 3.0 tan
Scheduler Model 2 - 87 0191 gray
IRT 100 Model 94 150 f.o.v emis: .98
IRT 377 Ag 42. 8-14 emis: .98

Scheduler Calibration

17 Dec 87

82°F

Time	BB T_a	Scheduler 1 Tan Crop	Scheduler 1 Tan Air	Scheduler 1 Tan RH	Scheduler 2 Gray Crop	Scheduler 2 Gray Air	Scheduler 2 Gray RH	IRT SN 100 T_{BB}	IRT SN 377 T_{BB}	IRT SN 377 T_{dif}
13:20	0	26.3	32.5	74.9	32	31.6	79.1	26		.1
13:22	10	27.8	53.0	84.3	30	50.0	84.9	24	33	9.8
13:24	20	29.0	69.4	86.6	29	68.1	85.6	23		19.9
13:26	30	30.1	87.3	89.2	28	86.9	87.1	22		30.5
13:28	40	27.3	104.1	76.5	32	104.7	78.2	26		40.1
⇒ 13:31	50	28.2	122.8	85.9	29	123.4	86.1	23		50.2
13:34	60	30.0	141.1	88.0	28	141.6	87.1	23		60.0
13:37	70	27.2	158.2	79.2	31	158.0	78.3	25		69.3
⇒ 13:39	65	27.7	~~147.5~~ 150.5	85.1	30	150.4	85.2	24	33	64.9
⇒ 13:43	60	30.0	~~116.5~~ 141.4	89.0	28	141.4	88.1	22		60.0
13:46	55	27.4	129.5	77.3	32	132.0	80.6	26		54.8
13:48	50	28.0	122.5	85.2	30	123.4	85.4	24		50.2
⇒ 13:51	45	30.0	~~113.9~~ 114.5	89.2	28	114.5	87.1	23		45.2
13:54	40	28.6	104.2	79.4	30	104.8	79.2	25		40.1
13:56	35	27.5	94.9	83.6	31	95.8	84.5	25		35.4
13:58	30	29.0	87.0	87.5	29	86.7	86.6	23		30.6
14:00	25	29.1	77.8	81.2	30	77.4	80.3	24	34	25.2
14:02	20	27.0	68.5	82.0	31	67.8	83.2	25		19.9
14:06	15	29.8	60.7	88.3	29	59.1	87.9	23	27	15.1
⇒ 14:09	10	27.0	~~50.3~~ ~~56.8~~	79.0	32	49.5	83.5	25		9.9
14:12	5	29.2	42.6	87.7	29	41.0	87.0	23		5.6
⇒ 14:16	0	28.3	~~33.4~~ ~~33.3~~	77.5	32	31.5	79.0	26	25	0.1

Time	T_a	T_w	RH
13:21	28.0	16.0	33
13:39	27.5	16.0	33
14:02	24.8	15.0	34
14:05	31.0	17.5	27
14:14	31.6	17.5	25

Scheduler 1 flaky - some readings were obviously wrong - noted them then drew line thru data and took another reading.

Scheduler Model 1 - 86-107 rev 3.0 tan
Scheduler Model 2 - 87 0191 gray
IRT 100 Model 94 150 f.o.v emis: .98 EVEREST
IRT 377 Ag 42 P-14 emis: .99

IR-CALIB

Scheduler Calibration

17 Dec 87

54°F

Time	BB	Ta	Scheduler 1 Tan Crop	Scheduler 1 Tan Air	Scheduler 1 Tan RH	Scheduler 2 Gray Crop	Scheduler 2 Gray Air	Scheduler 2 Gray RH		IRT SN100 T_{BB}	IRT
9:58	0	12.9	30.3	55.5	58.0	31.6	53.7	53.0		-.5	
	10	11.5	29.7	51.2	57	49.3	51.3	55		10.0	
10:04	20	12.2	67.5	51.1	57	67.9	53.4	54		20.4	
10:07	30	11.0	85.5	52.2	59	86.6	54.4	56		30.8	
10:09	40	12.5	104.2	55.0	56	105.4	53.0	54		41.0	
10:12	50	11.0	121.3	50.3	60	123.7	52.5	57		51.2	
10:14	60	12.3	141.0	55.4	58	141.8	56.1	55		61.55	
10:18	70	11.2	159.8	51.6	57	159.5	54.5	56	60	72.1	
10:21	65	12.8	150.4	55.9	57	150.6	53.9	54		67.0	
10:23	60	11.6	140.8	52.3	57	141.8	52.6	55		61.5	
10:25	55	11.2	127.8	53.4	58	132.9	54.4	56		56.4	
10:27	50	12.8	121.7	56.8	57	124.2	55.5	54		51.4	
10:29	45	11.8	113.3	52.2	57	114.8	52.7	55		46.3	
10:32	40	11.8	104.2	54.4	58	105.6	56.0	55		41.1	
10:35	35	12.2	94.4	53.3	57	96.1	53.2	55	53	35.8	
10:37	30	11.0	85.5	51.5	57	86.8	53.3	56		30.7	
10:39	25	12.4	76.7	55.4	58	77.5	56.3	54		25.6	
10:43	20	11.0	67.6	51.7	58	68.0	53.4	56		20.3	
10:45	15	12.6	59.2	56.4	57	58.8	54.8	54	56	15.5	
10:48	10	11.5	49.9	51.5	57	49.1	51.9	55		9.8	
10:52	5	12.6	42.1	56.0	58	40.5	54.4	54		4.6	
10:55	0	11.2	32.7	51.6	58	31.4	53.3	56		+0.7	

Time	Ta	Tw	%RH
10:19	11.5	7.6	60
10:34	14.5	9.5	53
10:45	12.7	8.8	56

C. Creelman
Lee Clark

Scheduler Model 1 - 86-107 rev 3.0 tan
Scheduler Model 2 - 870191 gray
IRT 100 Model 94 150 C.O.V emis: .98
IRT 377 Ag 42. 8-14 ? emis: .98

- IRT's not on constantly
- IRT's not on constantly

Fig. 3

IR-GUN CALIBRATION

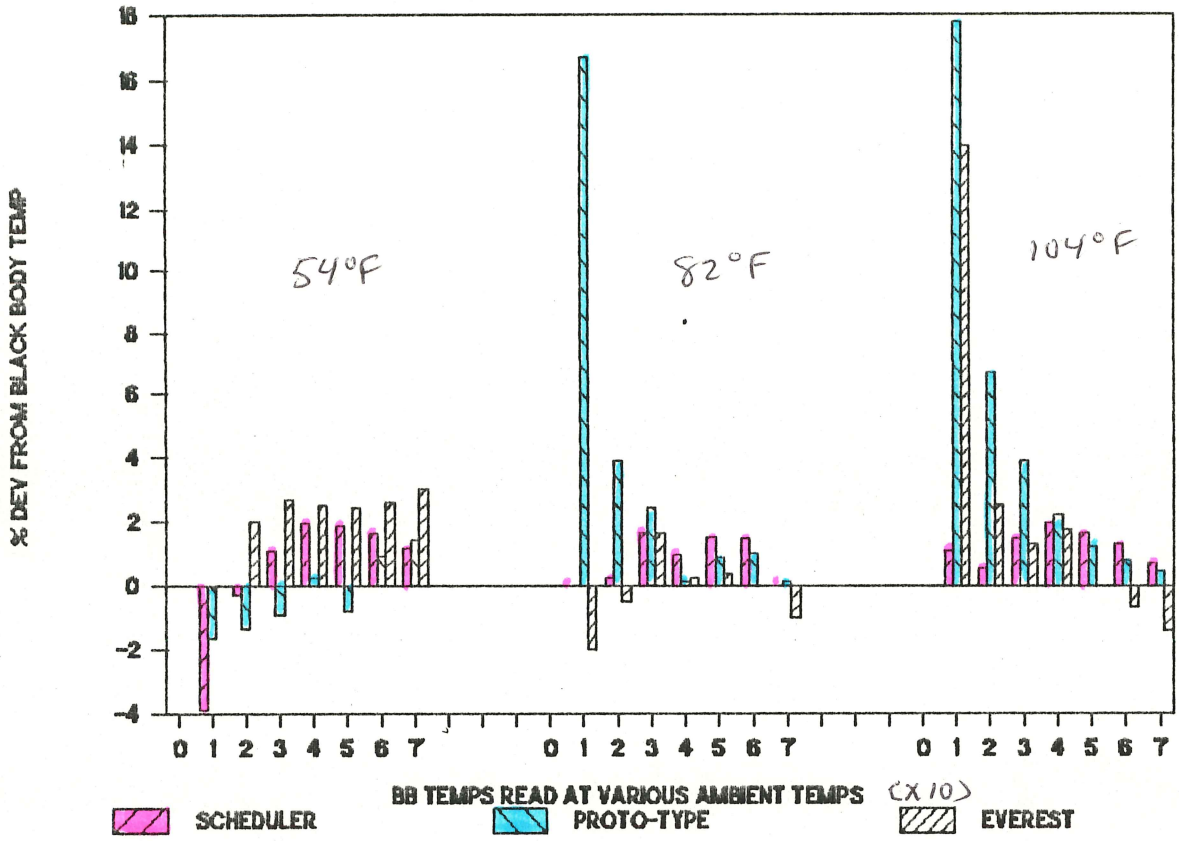
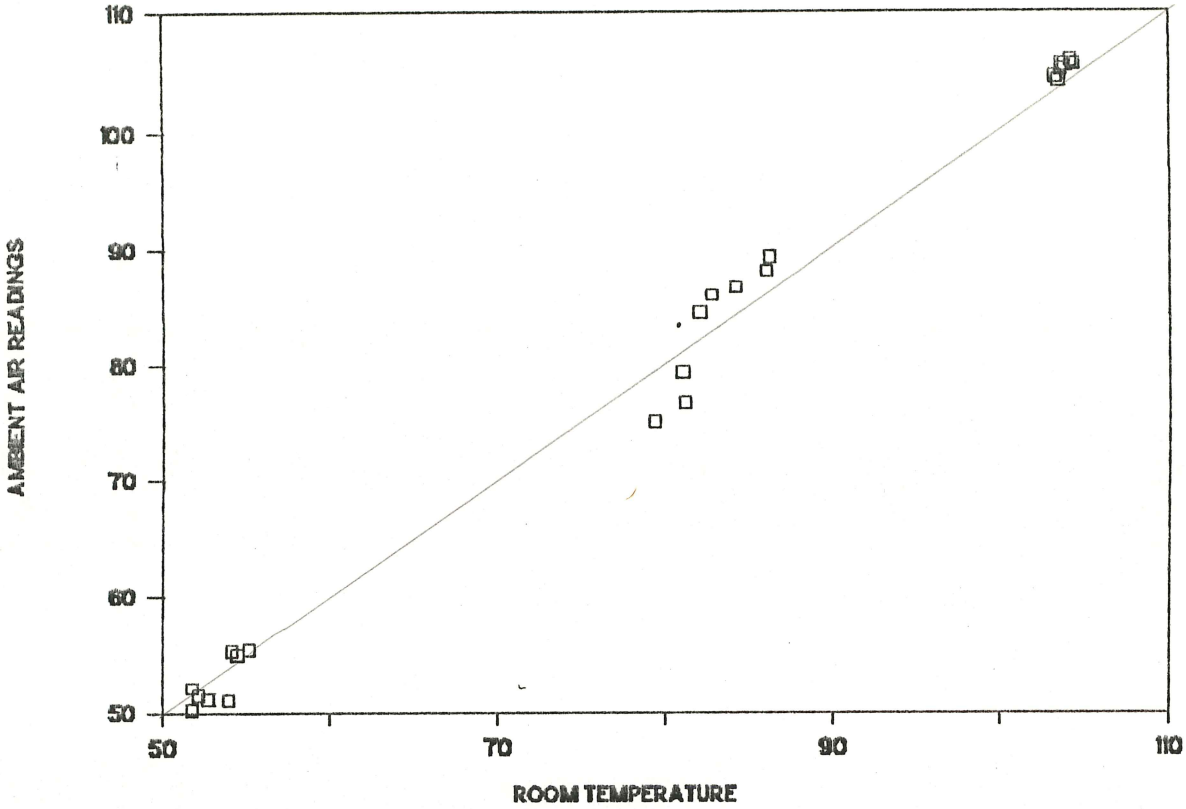


Fig 2

SCHEDULER CALIBRATION

PROTO-TYPE GUN



SCHEDULER CALIBRATION

MONTIERTH GUN

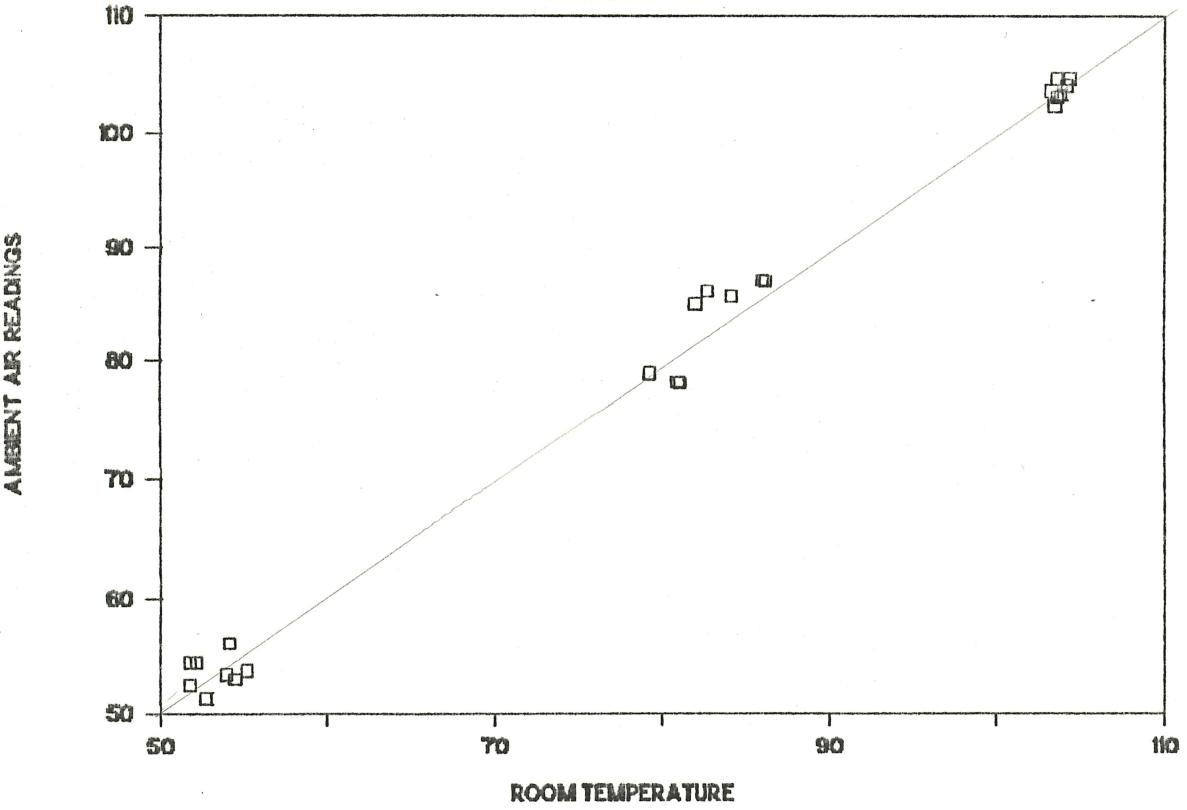
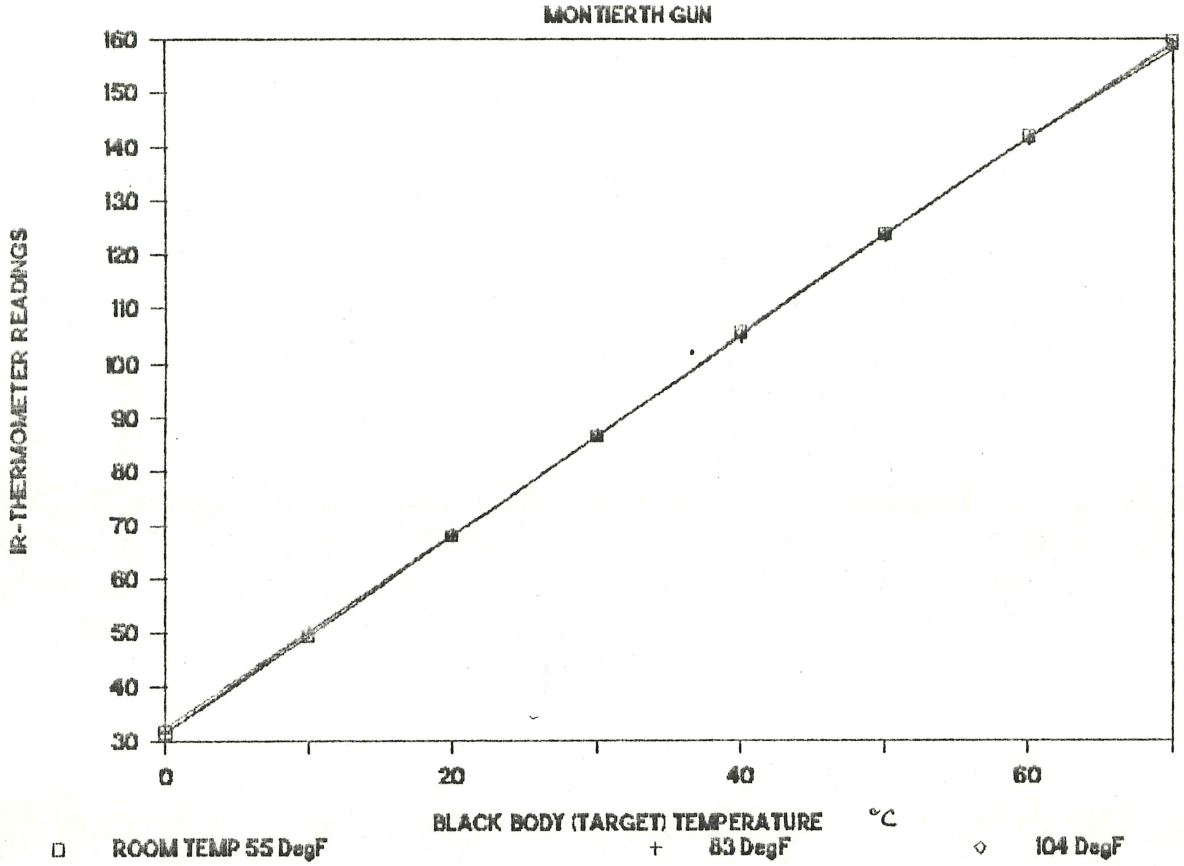


Fig. 1

SCHEDULER CALIBRATION



Safford Agricultural Center
P.O. Box 1015
Safford, AZ 85548
30 Dec 1987

Bronson Gardner
Standard Oil
Engineered Materials Company
6180 Cochran Road
P.O. Box 391316
Solon, Ohio 44139

Dear Bronson,

I am sending you a copy of the raw data from the test in the Water Research Lab along with a couple of graphs that I drew up from the data and a copy of the letter I sent to Tom Fairweather of ProAg in Fresno. Something that needs to be looked at is the relative humidity readings. There seems to be a fair discrepancy between the guns and the psychrometer readings in the lab.

Because of the glitches that can occur with the proto-type gun that I have I would like to request a different loaner for the 1988 season. I plan to continue the irrigation scheduling research on both wheat and cotton. I would like to request a research grant of $1000 to extend the research into evaluating stress levels of cotton and timing of plant growth regulators and defoliants. This grant would help build up our funds so we could purchase a unit in the future.

Sorry to be so brief, but quarterly reports and annual faculty review reports are pressing. As I get the cotton data analyzed from the past season I'll be in touch again.

Sincerely

Lee

Lee J. Clark

Pistol Characterization Process for 1987 Scheduler Plant Stress Monitor

Pistols should be fully assembled with potting, all modifications and Strain Relieved coil cord.

1.) Preheat Oven or chamber to 40°C (104°F)

2.) Heat complete pistol assemblies a minimum of 30 minutes.

3.) Set Black Body emitter to 25°C and allow to equilibrate.

4.)-Remove heated pistol from oven.
- Plug Pistol into Data Logger Unit.
- Aim pistol at black body emitter face.
- Turn Data Logger unit on and set to Print mode, °C
(Make sure printer is on line, has paper and is attached to Data Logger printer port.)

5.) Let Pistol and Data Logger run for a minimum of 20min until pistol assembly is equilibrated to Ambient Conditions (room Temp

JJ 4-8-88

6.)- Turn off Data Logger, Printer off line
- Remove pistol from Data Logger
- Remove printout from Printer
- Record pistol serial number at top of printout page

7.)- Find maximum rate of change
(second column from right edge, number of highest magnitude)

- Circle maximum rate of change value and the correction factor to its Right.

8.) - Record the correction factor at the top of the printout page near the serial number.

- Add 50 to the absolute value of the correction factor.
This total becomes the Data Value Number.
(should be between 100 and 900)
- Record the Data Value Number on the units paperwork and inside pistol handle.

APPENDIX

TEMPERATURE COMPENSATION

Adjusting the output of an infrared thermometer for changes in the physical temperature of the infrared sensor is called temperature compensation. In the past, some companies have developed designs which accomplish temperature compensation through the use of mechanical choppers. Recent designs allow for temperature compensation without the use of mechanical choppers. Graham et al. (1989) show that an accuracy of at least 0.2 C can be maintained even when an unprotected, uninsulated, non-mechanically chopped infrared sensor is exposed to a step change of 20 C in ambient conditions.

The Scheduler^{R} infrared thermometer is temperature compensated, although it does not contain a mechanical chopper. Not all infrared thermometers without a mechanical chopper are temperature compensated. The caution that Jackson (1982) gave is still applicable : "It is highly recommended that a potential purchaser determine whether an adequate temperature compensation circuit is an integral part of any instrument intended for field use" . To this we can now add that temperature compensation can be achieved through the use of mechnical choppers or through the use of modern thermal designs and computing techniques.

HOW TO CALIBRATE AN INFRARED THERMOMETER

How an IRT Works

The general equation for calibrating an IRT is:

$$IRT = T_D + (T_T - T_D) \quad (1)$$

T_D = Internal instrument temperature
$(T_T - T_D)$ = difference in temperature between a target and the internal instrument temperature

$(T_T - T_D)$ is proportional to the voltage output (V) of an IR - detector, a device similar in function to a photodiode, except it is sensitive to heat energy instead of light. Thus,

$$IRT = T_D + K_1(V) + K_2(V)^2 \ . \ . \ . \quad (2)$$

where $K_1 + K_2$ are calibration coefficients to fit voltage output to measured quantities of $(T_T - T_D)$. When $T_T = T_D$, then V = O.

Static Calibration (All temperatures are stable)

Equation 2 shows that in order to calibrate an IRT properly, it is necessary to separately calibrate the T_D and $(T_T - T_D)$ functions. T_D can be measured with a thermister or thermocouple implanted physically close to the IR-detector.

To calibrate T_D, the temperature of a black-body (T_B) must be known. If the black-body and IRT are equilibrated to the same temperature, then the output of equation 2 = T_D since V = O. This reading can be compared directly with T_B. It is important to note, this type of calibration provides absolutely no information on the performance of the IR detector, only the accuracy of the internal reference temperature. Several values of T_D should be used.

To calibrate the detector, it is necessary to have the black body warmer or cooler than T_D so that V ranges from very positive to very negative. It is necessary to hold T_D at several values between the expected operating limits and adjust the black-body readings around T_D. V can then be calibrated to $(T_B - T_D)$.

Dynamic Calibration

What if the IR is exposed to changes in ambient temperature? This is the normal operating condition. Very seldom are IRTs used in completely stable thermal environments. This makes it necessary to continuously measure internal instrument temperature. This can be done mechanically with a chopper or with a "software-chopper", additional terms added to equation 2 to compensate for the dynamic behavior of the system. Mechanical choppers provide a high-degree of accuracy, but are subject to serious problems in durability, especially if the IRT is exposed to rough handling or extremes in temperature. Software choppers are only slightly less precise than mechanical choppers. Since IRTs with software choppers have no moving parts, they can be made rugged, durable and less expensive to repair than mechanically chopped IRTs.

Blackbody Type

Two types of blackbodies can be used: 1) Temperature regulated blackbodies, which cost several thousand dollars or; 2) ambient temperature blackbodies, which cost a few hundred dollars. The previous discussion shows that blackbody temperatures must be warmer or cooler than ambient temperature in order to test the true accuracy of an IRT. A false sense of security will result if ambient temperature blackbodies are used, since the performance of the detector is not tested when a blackbody and an infrared thermometer are equilibrated to similar temperatures. The use of ambient temperature blackbodies is further complicated by the fact that internal IRT temperatures are not displayed. Accurate calibration of an infrared thermometer dictates that temperature regulated blackbodies must be used for calibration purposes. Temperature regulation can be achieved using water baths or thermo-electric techniques.

SCHEDULER BENEFITS

- Detect stress days before visible symptoms occur
- Directly measure how the plant is feeling
- Minimize nutrient leaching
- Save on labor for field monitoring
- Avoid problems caused by over-irrigation
- Avoid under irrigation
- Optimize the water/yield relation
- Measure information on air temperature, relative humidity, sunlight or surface temperature for other applications
- Store information collected directly into a computer
- Stress crops at certain stages if desired
- Monitor crop reaction to chemical applications
- Speed up the decision making process